Trans. Inst. Indian Geographers
Vol. 31, No. 1, 2009

Scour depth estimation based on the physical properties of soil along the tributaries of river Pravara, Maharashtra.

Veena U. Joshi

Abstract

The estimation of scour depth around bridge piers and abutments is a common practice in Engineering Geology. The local lowering of the riverbeds around the elements of a bridge such as piers, abutments and spur dikes is what is termed as 'scour', which is influenced by the local factors prevailing in a particular area. In the present paper, this concept has been applied to riverine badland topography to determine the possible depth up to which the river will sour the sediments. Lacey-Inglis's Method has been adopted to estimate the scour depth. The soil physical properties as well as K erodibility index suggest that these soils are fairly to moderately erodible and the estimated scour depth is between 3-4 m. Though the calculated values show extreme conditions under the prevailing set of conditions, it gives a fairly good estimate of the sediment's erodible depth. Recently the area is undergoing rapid land reclamation for the purpose of agriculture, hence evaluation of its properties are relevant to understand the susceptibility of the sediments to erosion.

Key Words : *Lacey-Inglis's Method, scour depth, erodibility, land reclamation, soil physical properties.*

Introduction

In an agricultural country like India, land undoubtedly forms one of the most important resources. In order to cope with the pressure of population, every bit of available land has been brought under various types of uses, which put a heavy pressure on the land. In the last few decades, reclamation of land for the purpose of agriculture has become a common trend in different parts of the country. What is overlooked very often is that unplanned and ill-advised landuse practices disturbs the fragile balance that exists in the landscape which therefore does more harm than good to the landscape in the long run, by making the land vulnerable to erosion. Hence it is a matter of utmost importance to understand various properties of the soil that we are dealing with, before putting it for any type of landuse practices, especially agriculture.

The area under review is a deeply dissected alluvial tract that extends for several km downstream along two tributaries of River Pravara (Godavari Basin) namely Adula River and Mahalungi River in Western Maharashtra, India. The location map of the study area is depicted in Fig 1. The region

is covered by a dense network of gullies and resembles a badland in appearance. The thickness of the alluvium is around 4-10 m. The area covers approximately an area of 276 sq km. Both the streams in their upper reaches flow through narrow and fairly deep gorges. The total stretch of the two streams within the study area is 18 km and 20 km respectively. All along these stretches, the banks are severely dissected by gullies forming badlands. The badland disappears abruptly in the confluence zone, as abruptly as it started behind a dam in the upper reach. The average height of the basin is 700 m ASL. As expected these gullies are short and V-shaped (Fig 2). The area receives about 600 mm of rainfall a year. Natural vegetation is in the form of thorny acacia vegetation which is typical of semi-arid region.

The badland topography is found along the immediate banks of the rivers. It is a natural badland, but recently the region sees a lot of human activities in the form of agriculture and related activities. Presently these areas are undergoing rapid erosion which is apparent from the deeply dissected nature of the topography. Badlands are formed in variety of environments. Geomorphologically they are found in the hillslope pediment zones and also along the riverbanks. Their formation is associated with certain climatic and sedimentological characteristics (Imesson et al 1982). These types of landscape occur mostly in such areas that are characterized by a short seasonal rainfall followed by a long and dry season. Since the present badlands are in the immediate vicinity of the river, their morphology and characteristics are directly controlled by the river.

The paper has dual objectives. 1 - to evaluate the physical and textural properties of these sediments in order to estimate its erodibility and 2 – to estimate the scour depth of these sediments.

The estimation of scour depth around bridge piers and abutments is a common practice in Engineering Geology. During the construction of a bridge, the main cause of concern is the stability of the bridge, which is greatly affected by the lowering of riverbed level caused by the river flow around the bridge elements. This local lowering of the riverbeds around the elements of a bridge such as piers, abutments and spur dikes is what is termed as 'scour'. The scour process involves a complex three-dimensional mechanism of flow, as well as sediment transport (Kothyari 2006). Therefore the estimation of the scour extent and its depth at the bridge sites are major concern for the bridge designers. Several studies have been conducted in India on mechanism of scour around bridge piers (Kothyari et al 1992 a, Vittal et al 1996, Kumar et al 2001and Ansari et al 2002).

Correct estimation of the depth of scour below the streambed at the stage of design is important in bridge designing, since this determines the founding levels of the bridge elements (Kothyari and Ranga Raju 2001). In other words, the scour depth represents the top layer of the soil around the bridge elements, which can be eroded by the river under a set of conditions. The same concept has been applied in the present context to estimate the possible scour depth of the alluvial sediments formed along the banks of River Pravara and its tributaries, in Maharashtra.

Table 1: Soil Physical Properties of the Undisturbed Samples

Bore Hole	Dst	Nmc %	Fdd	Sp.Gr.	Atterberg's Limits LL %	PL %	SL %	Mechanical Analysis % G	% S	% silt	% clay	Direct Shear Cohen C Kg/ cm^2	Angle of Internal Friction	Dfs	Permeability (K)
M-1	1	18	1.42	2.51	NP	NP	-	20.0	62.0	16.00	2.00	0	29	-	1.10*10 -3
M-1	2	10	1.34	2.47	NP	NP	-	44.0	29.0	24.00	3.00	0	30	-	1.12*10 -3
M-1	3	3.4	1.75	2.62	NP	NP	-	17.0	66.0	14.00	3.00	0	28	-	1.32*10 -3
M-1	4	5.1	1.51	2.52	NP	NP	-	19.0	68.0	13.00	0.00	0	32	-	1.43* 10 -3
vertical	1	11	1.38	2.57	NP	NP	-	19.0	59.0	20.00	2.00	0	34	-	1.25* 10 -3
vertical	2	3.3	1.72	2.55	NP	NP	-	45.0	35.0	20.00	0.00	0	33	-	1.42*10 -3
vertical	3	13	1.11	2.11	NP	29	-	3.0	36.0	45.00	16.00	0.12	27	-	1.35*10 -4
vertical	4	5.4	1.55	2.49	NP	NP	-	35.0	58.0	7.00	0.00	0	30	-	1.47* 10-3
vertical	5	7.4	1.62	2.52	NP	NP	-	25.0	68.0	7.00	0.00	0	33	-	1.32* 10 -3
R Gang	1	7.4	1.86	2.13	35	22	18.00	0.0	32.0	50.00	18.00	0.13	28	25	1.334* 10 -3
R Gang	2	21	1.47	2.48	NP	NP	-	4.0	53.0	33.00	10.00	0	31	-	1.35* 10 -3
R Gang	3	13	1.87	1.98	55	12	12.00	2.0	8.0	77.00	13.00	0.13	27	30	1.25* 10 -6
dam B	1	9.8	1.99	2.38	NP	NP	-	11.0	58.0	27.00	4.00	0	34	-	1.35* 10 -3
dam B	2	40	1.56	2.17	66	21	8.00	4.0	9.0	75.00	12.00	0.13	26	40	1.48* 10 -6
dam B	3	25	1.10	2.03	NP	27	-	3.0	10.0	65.00	22.00	0.13	26	-	1.36* 10 -3
dam B	4	26	1.19	2.15	NP	24	-	0	22.00	61.00	17.00	0.12	27	-	1.35* 10 -3

It is the hypothesis of the paper that the scour depth of these soils represents the top layer that will be easily erodible under a particular set of conditions prevailing in these areas. Hence an attempt has been made in this paper to estimate the scour depth of these sediments by employing an Engineering technique called 'Lacey-Inglis's Method'.

Materials and Methods

In order to investigate the physical and mechanical properties of the sediments of the badland under review a total of 25 samples (16 undisturbed and 9 disturbed samples) were collected from different locations within the study area. Following tests were performed at Soiltech India Pvt. Ltd, Pune, as per relevant IS (Indian Standard) 2720;

- Natural moisture content
- Field dry density
- Specific gravity
- Differential free swell
- Atteberg's Limits (Liquid and plastic limit tests)
- Direct shear test
- Permeability
- Mechanical analysis including hydrometer analysis

In order to calculate the mean scour depth, the discharge data was obtained in the field at three different cross-sections from where samples have been collected.

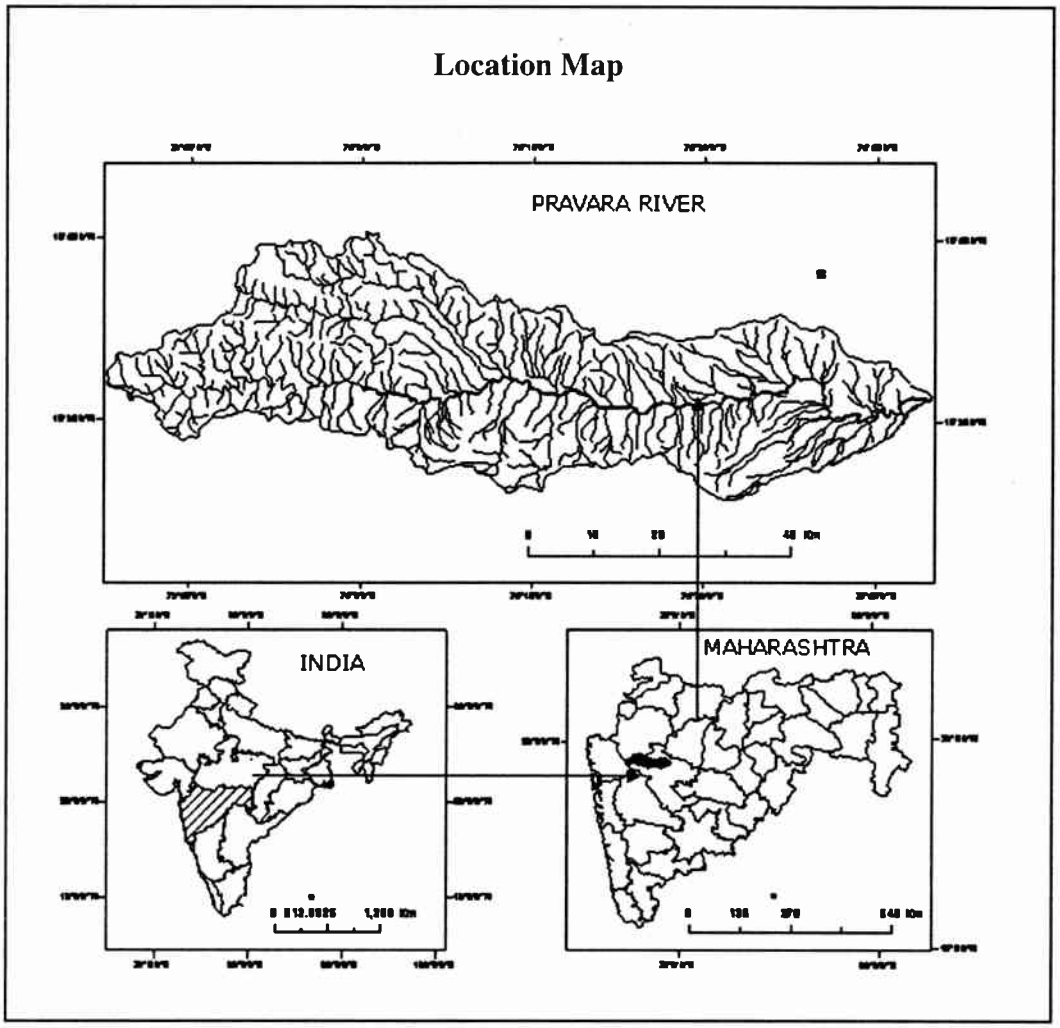

Fig 1: Location map of the study area is depicted in this diagram

Silt factors have been taken from the IRC: 5-1998.

Results

Soil chemical and mineralogical properties have direct influence on the strength of soil to erosion. High ESP (Exchangeable Sodium Percentage) causes the sediments to slack when it comes in direct contact with water (Phillips 1998) Presence of swelling smectite clays also is one of the factors inducing soil degradation on the badlands (Imesson et al 1982). The focus of the present study is only on the soil physical properties and their influence in erodibility

of these sediments. Hence the description of the soil physical parameters is outlined before estimating the scour depth of the sediments under review. The overall results of various soil physical properties for the undisturbed samples are listed in Table 1 and for disturbed samples are shown in Table 2.

Natural moisture content

Natural moisture content is the percentage of moisture (water) in the soil by weight in the natural state. It is simply calculated by taking the difference in the weight of the soil sample in the natural state and after oven dried. Value between 0 and 10 is dry soil, between 10 and 20 is moist and beyond that is wet soil according to IS classification. Out of the 16 UDS (undisturbed sample), seven samples are dry, five are moist and rest are wet, in their natural state. For DST (disturbed sample) except for two of them that are moist, the samples are dry samples.

Field dry density

Field dry density can be obtained only for UDS. It is expressed as g/cm^3 of the sample. Majority of the samples demonstrate low density, few are medium and only three of them show high density (value above 1.8 g/cm^3)

Atteberg's Limits

Atteberg's limits, most commonly plastic and liquid limits are an integral part of several engineering classification systems to characterize fine grained soil. As fine clayey soils are mixed with excessive water, it flows like semi-liquid. As the material dries, it passes through a plastic, semi-solid and then solid state. There is reduction in both the water and void ratio as the material shrinks. The water content at which the soil changes from liquid to plastic state is Liquid Limit (LL) and the water content at which soil changes from a plastic to semi-solid state is the Plastic

Table 2: Soil Physical Properties of the Disturbed Samples

Bore Hole	Dst	Nmc %	Fdd	Sp.Gr.	Atterberg's Limits LL %	PL %	SL %	Mechanical Analysis % G	% S	% silt	% clay	Direct Shear Cohen C Kg/ cm^2	Angle of Internal Friction	Dfs	Permeability (K)
profile1	1	6.2	_	2.16	NP	NP	-	2.0	47.0	47.00	4.00	-	-	-	1.25* 10 -3
profile1	2	5.5	_	2.58	NP	NP	-	28.0	61.0	11.00	0.00	-	-	-	1.30* 10 -3
profile2	3	6.3	_	2.57	NP	NP	-	7.0	58.0	33.00	2.00	-	-	-	1.35* 10 -3
profile2	4	10	_	2.61	NP	NP	-	12.0	59.0	28.00	1.00	-	-	-	1.28* 10 -3
profile2	5	21	_	2.48	NP	NP	-	8.0	56.0	35.00	1.00	-	-	-	1.30* 10 -3
profile3	6	2.1	_	2.58	NP	NP	-	15.0	84.0	1.00	0.00	-	-	-	1.40* 10 -3
profile3	7	3.7	_	2.51	NP	NP	-	22.0	53.0	22.00	3.00	-	-	-	1.35* 10 -3
profile1	1	13	_	1.97	NP	30	-	5.0	22.0	46.00	27.00	-	-	-	1.20* 10 -3
profile2	2	17	_	2.52	NP	33	-	33.0	15.0	47.00	5.00	-	-	-	1.35* 10 -3

Limit (PL). Although these limits represent water content, they are expressed without the percent designation. Plasticity index (PI) is the difference between LL and PL and represents the moisture range in which plastic properties dominate soil behavior. A high PI indicates that the material has significant clay content, while a low plasticity index near 0 indicates that the material is non-plastic such as silt (ASTM D 424, American Society for Testing and Materials).

Plasticity index of almost all the samples under investigation are non-plastic in characteristics. One sample from Ganga Nala shows LL 35, which is low compressibility soil. It shows shrinkage limit of 18. LL >50 is high compressibility soil, which is found in another sample of the same site. A single sample from Bhojapur Dam site has high value of 66 LL with low shrinkage limit of 8 as expected. As the liquid limit of the soil is raised, the shrinkage limit automatically decreases. Shrinkage limit (ASTM, D 427) is that moisture content expressed in percentage of the weight of the oven dried sample, at which reduction in moisture content will not cause a decrease in the volume of the soil, but with an increase in moisture content, will cause an increase in volume of soil mass. Non-plastic samples indicate that samples are easily breakable or in other words they are susceptible to external forces of erosion easily.

Specific Gravity:

Specific gravity is defined as the ratio of the weight of an equal volume of distilled water at that temperature both weights taken in air (ASTM D854). The specific gravity of soil solids is used in calculating the phase relationships of soils, such as void ratio and degree of saturation. It is used to calculate the density of the soil solids. This is done by multiplying its specific gravity by the density of water (at proper temperature). The specific gravity of the soil particles lie usually within the range of 2.65 to 2.85. Soils containing organic matter and porous particles may have specific gravity values below 2.0. Soils having heavy substances may have values above 3.0. The sediments under investigation result in values lower than 2.6 for majority of the samples (Table 1). The highly porous nature of the soil may have been responsible for the low specific gravity of these samples.

Differential free swell (DFS)

This is an index of expansiveness of soil. Values below 20 is less expansive, between 20 and 35 are moderate, 35 and 50 are high and above 50 is very high. Since majority of the samples are non-plastic, they have very low swell potential as can be seen in Table 1.1. There is a direct relationship between Atteberg's limit with the DFS. Higher the PL and LL, higher is the DFS also.

Direct shear test

The shear strength of the soil is resistance to deformation by continuous shear displacement of soil particles. The test is generally performed to determine consolidated drained shear strength of a sandy to silty soil. The shear strength is needed for engineering purposes such

Table 3: Erodibility Index (K Value)

Sr No	SF*	S*	OM*	Structure	Permeability	K*
1	18	62	0.06	Coarser Granular	Mod-Rapid	0.13
2	27	29	0.06	Fine Granular	Mod-Rapid	0.09
3	25	66	0.12	Coarser Granular	Rapid	0.17
4	30	50	0.24	Coarser Granular	Rapid	0.16
5	22	59	0.12	Coarser Granular	Rapid	0.13
6	20	35	0.6	Fine Granular	Mod-Rapid	0.08
7	61	36	0.21	Fine Granular	Mod-Rapid	0.5
8	7	58	0.06	Coarser Granular	Mod-Rapid	0.08
9	70	35	0.18	Fine Granular	Mod-Rapid	0.61
10	68	32	0.06	Fine Granular	Mod-Rapid	0.53
11	43	53	0.54	Coarser Granular	Rapid	0.35
12	80	8	0.09	Very Fine Granular	Mod-Rapid	0.5
13	31	58	0.15	Coarser Granular	Rapid	0.19
14	87	9	0.12	Very Fine Granular	Mod-Rapid	0.6
15	65	10	0.06	Fine Granular	Mod-Rapid	0.4
16	61	22	0.18	Fine Granular	Mod-Rapid	0.43
17	51	46	0.12	Coarser Granular	Rapid	0.4
18	45.54	48	0.18	Coarser Granular	Rapid	0.34

SF: Silt + Fine Sand; S : Sand; OM: Organic Matter; K: Erodibility

as determining the stability of slopes or cuts, or finding out bearing capacity for foundations etc. In geomorphic context it is the resistance capacity of the soil to external erosional forces. This test is conducted only for the UDS. Shear strength can be separated into two components, such as c- cohesion between the surface of the soil particles and - friction between inter granular soil particles. The result of the test shows that the samples under review are cohesionless and friable soils.

Permeability

Soil permeability is the property of the soil pore system that allows fluid to flow. It is generally the pore sizes and their connectivity that determines whether a soil has high or low permeability. Water will flow easily through soil with large pores with good connectivity between them. Small pores with the same degree of connectivity would have lower permeability, because water would flow through the soil more slowly. It is possible to have zero permeability (no flow) in a high porosity soil if the pores are isolated (not connected). It is also possible to have zero permeability if the pores are

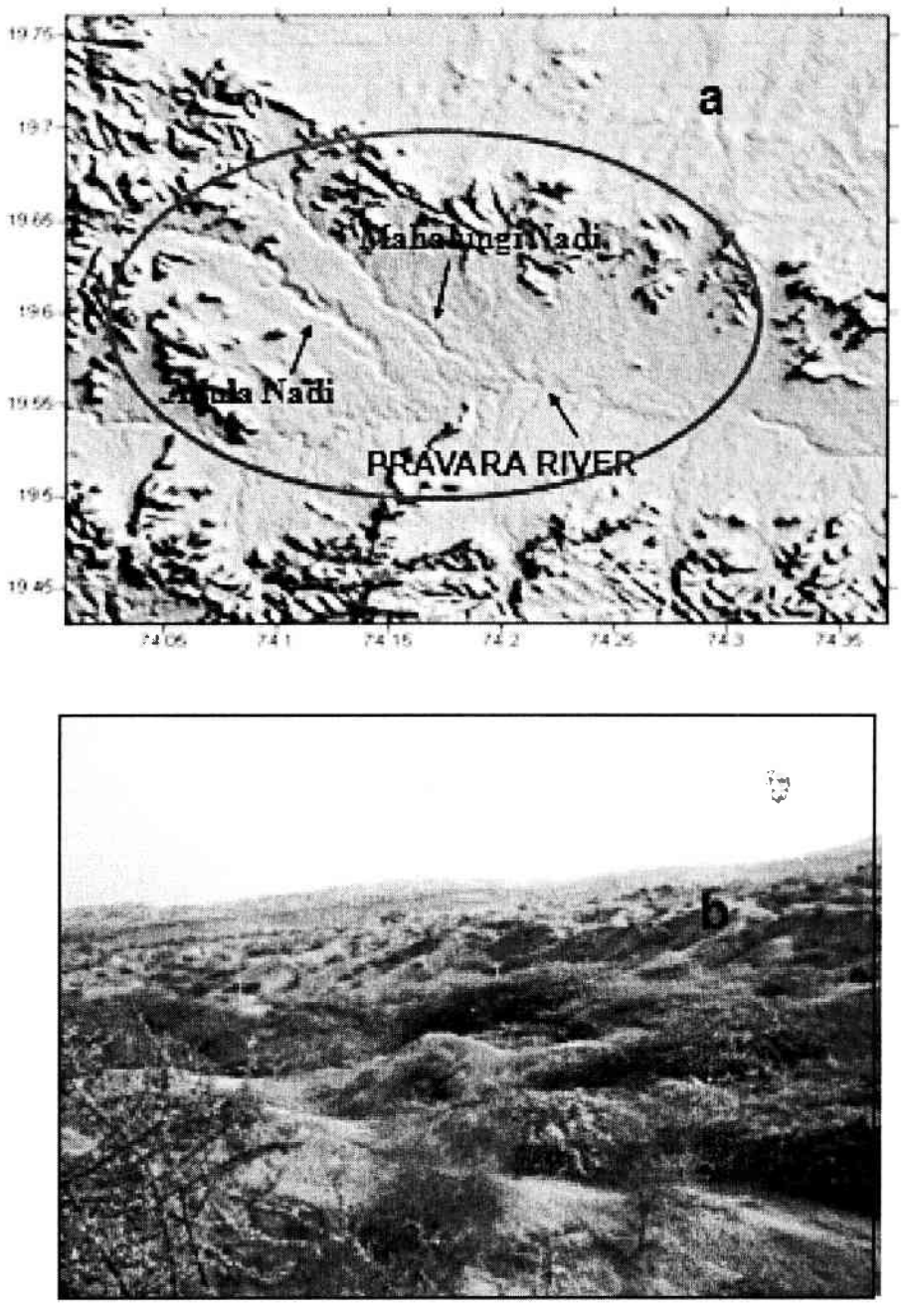

Fig 2 (a): Location of the two tributaries of Pravara River where badlands have been formed have been demarcated on the shaded relief map of the sudy area and (b) A field photo of the sample site.

very small, such as in clay. Majority of the samples of the study area indicate high permeability. Coarse textured soils tend to have large, well-connected pore spaces and hence high permeability. Similar is the case with the samples under investigation. Only a few clay rich sediments reveal low permeability, as the pore spaces get sealed after the soil becomes wet.

Textural Characteristics of Soil

Table indicates the percentage of grain size distribution of the samples and their category according to IS classification. Silty-sandy soil (SM) predominates the disturbed samples whereas undisturbed samples reveal equal number of silty-sandy soils with inorganic silt and clay samples. Silty sandy soils are high in permeability and clayey soils show medium to low permeablity, depending on their silt content. A distinct pattern can be observed in the grain size distribution of the samples. Bhojapur Dam site is located close to the source area of these streams and shows the predominance of inorganic silt or clay with both high and low liquid limits. Saikhindi site is situated roughly 18 km downstream from the previous site and is close to the confluence of Adula and Mahalungi Nadis. All the samples from this site are sandy silty samples with high permeability.

Soil Erodibility (K Index)

In order to evaluate the susceptibility of these sediments to erosion, the erodibility index has been estimated from Wischmeier et al's 1971 K-erodibility nomograph. The estimated values have been listed in Table 3.

Table 4: Design scours depths for the samples

Location	Silt Factor	Design Scour Depth (m)
M-1	1.25	3.26
M-1	1.5	3.06
M-1	1.25	3.26
M-1	1.25	3.26
Vertical	1.25	3.26
Vertical	1.50	3.06
Vertical	0.5	4.39
Vertical	1.25	3.26
Vertical	1.25	3.26
R Ganga	0.6	4.15
R Ganga	1.25	3.26
R Ganga	0.5	4.39
Dam B	1.5	3.06
Dam B	0.6	4.15
Dam B	0.6	4.15
Dam B	0.6	4.15
Profile 1	0.6	4.15
Profile 1	1.25	3.26
Profile 2	1.5	3.06
Profile 2	1.25	3.26
Profile 2	1.25	3.26
Profile 3	1.25	3.26
Profile 3	1.25	3.26
Profile 1	0.6	4.15
Profile 2	0.6	4.39

It is evident from the table that the estimated K values range from low, moderate to high. The organic content of these sediments are very low. Under such conditions, it is expected to find highly erodible soils but the highly permeable nature of the soil has contributed largely to the K values which are responsible for lower

K values. The overall assessment of the susceptibility of these sediments to erosion based on the soil physical properties and K erodility estimates suggests that these sediments are fairly to moderately highly erodible. Out of the 18 samples analysed, half of them show values of nearly 0.5, putting them in the category of moderately to fairly highly erodible soils. Such sediments respond to erosional agents readily when they are disturbed for agricultural purposes. The present site is undergoing rapid land reclamation for farming various crops. Hence an attempt has been made here to estimate the depth of these sediments that will be most prone to erosion under the existing climatic conditions.

Estimation of Mean Scour Depth

Lacey-Inglis's method of estimating regime depth of flow in loose bed alluvial rivers was first developed by Lacey in 1929 and later by Inglis in 1944 mainly based on the observation of canals in India and neighboring Pakistan. This technique is therefore used mainly in India for estimation of scour depth around bridge piers in alluvial channels. It has also been applied for design by Indian Road Congress and Indian Railways (Kothyari 2006). This is the first ever attempt to apply this technique in fluvial geomorphology research.

The mean scour depth below highest flood level (HFL) for natural channels flowing over scourable bed can be calculated theoretically from the following equation:

$$d_{sm}=1.34(D_b^2/K_{sf})^{1/3}$$

(IRS – 5, 1985)

Where

d_{sm} = Mean depth of scour in meters below the highest flood level.

D_b = Discharge in cumecs per meter width.

K_{sf} = Silt factor determined for the stratum based on weighted mean diameter of particle in mm.

Since the samples were representative of the area, attempt was made to generalize the silt factor.

With reference to IRS clause 110.1.4.2 for design of floor protection works, for raft foundations and shallow foundations the following scour values have been adopted.

1. In a straight reach 1.27 d_{sm}
2. At a moderate bend 1.50 d_{sm}
3. At a severe bend 1.75 d_{sm}
4. At a straight angled bend 2.0 d_{sm}

The design scour depths at different locations have been obtained and the results are outlined in Table 4.

Discussion and Conclusion

Badlands are the regions that are deeply dissected and hummocky in appearance. As the name suggests they are Bad Lands that is not good for any economic use. However, due to the increasing pressure of population, these landscapes also have been brought under reclamation for the purpose of agriculture in the past few decades. The results of the variables detected and indices calculated for the sediments indicate that the sediments are moderately to fairly highly erodible. Erodibility of soil is the function of several factors put together, a combined

effect of soil chemical, physical and mineralogical properties. The importance of soil chemical properties and their influence on soil strength has been emphasized by many authors (eg Imesson and Verstraten 1985, Missopollinos et al, 1988 and Rienks et al, 2000 etc). The influence of shrink-swell smectite clays on the soil properties are also a widely known concept in soil science today (Donahue et al, 1987). In almost all the cases it is found that these factors work in certain combinations and seldom are they operate alone. In the present study, the evaluation of the soil erodibility is done on the basis of the soil physical properties. The results of the calculated indices demonstrate that 1) the natural moisture content of the sediments under review are very less 2) field dry density also reveals that majority of the samples has low density 3) Plasticity index implies that sediments are non-plastic and hence are not cohesive 4) Non-plastic samples usually show low swelling capacity and the present samples also reveal this trend as can be seen by the values of differential swelling tests 5) Permeability is high for almost all the samples and the 6) the textural analysis indicates the predominance of silty-sandy soils. In short, all these results point towards the fact that these sediments are by no means cohesive sediments and can be considered as erodible. The erodibility index also indicates a similar finding.

The mean scour depths of the sediments range in value between 3.06 m and 4.39 m. In other words, if the sediments would have been under water, the top 4 m is the portion most susceptible to erosion under the set of conditions prevailing in this area. Though this represents extreme condition, these sediments are bank sediments and are directly in contact with water, therefore assuming a situation close to the scouring conditions along the bridge foundations cannot be totally irrelevant. Lacey-Inglis's method is valid for sandy rivers of meandering type, with sediment size of about 0.15 mm to 0.43 mm (Chitale 1993). The present site falls under this category. Therefore it is a big question whether the present Landuse of the area with indiscriminate plowing and disturbing the soil upper layer is a wise idea or not in this area. The importance of additional land for agriculture to feed the ever-increasing population is understood, but to allow indiscriminate land reclamation and unplanned agriculture in this fragile and sensitive landscape is a doubt. Therefore, it is essential to look into these problems more seriously in future for a better tomorrow.

Acknowledgements

Soil physical parameters were detected at Soiltech India Pvt. Ltd. The author is very grateful to Mr. Ramesh Kulkarni and Mr. Siddarth Kulkarni of the same institute for their help in the analysis.

References

Ansari, S.A, Kothyari, U.C and Rangaraju, K.C (2002) – Influence of cohesion on scour around bridge piers. *Jour. of Hyd. Res. Inter. Assn. of Hydraulic Res.* 40 (6) pp 717-729

Chitale, S.V (1993) – Indian practice of scour estimation-limitations. *Jour. of Irri. and Power (CBIP)* 50 (4) April

Donahue R.L, Miller R.W and Shickluna J.C (1987) – *Soils*, Prentice Hall of India, New Delhi 371-372

Imesson A.C, Kwaad F.J.P.M and Verstraten J.M (1982) – *The relationship of soil physical and chemical properties to the development of badlands in Morocco*. In R.B Bryan and A Yair (eds) *Badland Geomorphology and Piping*, Geobooks, Norwich 47-70

Imesson A.C and Verstraten J.M (1985) – The erodibility of highly calcareous soil material from Southern Spain. *Catena*, 12, pp 291-306.

Inglis C.C (1944) – *Maximum depth of scour at heads of guide banks, groyens, pier noses and downstream of bridges*. Annual Report (Technical) CWPRS, Pune

IRC (1998) – *Standard specifications and code practice for road bridges* section 1. IRC – 5,1998.

Kothyari U.C (2006) – An assessment of Indian practice for estimation of scour around bridge piers and abutements. *Advances in bridge engineering* 24-25 pp 89-100

Kothyari, U.C and Ranga Raju, K.G (2001) – Scour around spur dykes and bridge abutements. *Jour. of Hyd. Res. Inter. Assn. of Hydraulic Res* (IAHR) 39,4 pp 367-374

Lacey G (1929) – Stable channels in alluvium. *Jour. of Inst. of Engineers*. Paper no 4736. Vol. 229

Misopolinos N. D, Silleos N.G, Prodromou K.P (1988) – The influence of exchangeable Mg on certain physical soil properties in a number of Mg affected soils. *Catena*, 15, pp 127-136.

Phillips, C.P (1998) – The Badlands of Italy, a Vanishing Landscape?'. *Applied geography*, 18, 3. pp 243-257

Rienks S.M, Botha G.A and Hughes J.C (2000) – Some physical and chemical properties of sediments exposed in a gully (donga) in northern Kwazulu – Natal, South Africa and their relationship to erodibility of the colluvial layers. *Catena*, 39, pp 11-31

Wischmeier W.H, Johnson C.B and Cross B.V (1971) – A soil erodibility nomograph for farmland and construction sites. *Jour.of Soil and Wat. Cons* 26, pp 189-193.

Dr. Veena U. Joshi
Dept. of Geography, University of Pune
Pune 411 007
Email: vujoshi@unipune.ernet.in